Bode 100 - Application Note

DC Biased Inductance Measurement

using the DC1000 Current Source

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Note: Basic procedures such as setting-up, adjusting and calibrating the Bode 100 are described in the Bode 100 user manual. You can download the Bode 100 user manual at www.omicron-lab.com/

Note: All measurements in this application note have been performed with the Bode Analyzer Suite V3.21. Use this version or a higher version to perform the measurements shown in this document. You can download the latest version at www.omicron-lab.com/

1 Introduction

This application note shows how to easily measure the electrical behaviour of inductors with dc current bias using the Bode 100 Vector Network Analyzer (VNA) in conjunction with the DC1000 current source, a third party device from Voltech (www.voltech.com). The DC1000 is a current source specially designed for current biasing with a high output impedance over a wide frequency range.

Three different inductors are measured and the behavior of their inductances with dc current is compared. After that, the measurement error induced by the current source is discussed.

The inductance of an inductor can depend on the applied current. The correlation between the magnetic flux density (B) and the magnetic field strength (H) is given by the equation

$$B = \mu H$$

where µ is the permeability of the magnetic material. Due to saturation effects in a magnetic core the permeability can decrease with increasing magnetic field strength which can result in a similar dependency as shown in Figure 1. Note that hysteresis effects are neglected.

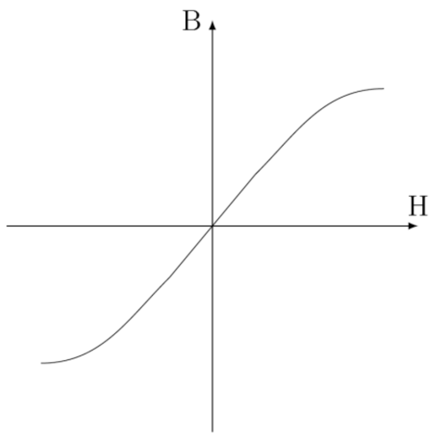

Figure 1: Magnetic flux density (B) vs. magnetic field strength (H)

The inductance is proportional to the permeability and the magnetic field strength is proportional to the current, thus the inductance depends on the applied current.

$$H \sim I$$

$$L \sim \mu$$

$$L = f(I)$$

In power electronics, inductors are often operated with dc bias. Inductance measurements with dc bias can therefore give valuable information about the inductor's behavior during the operation.

2 Measurement Setup and Preparation

The inductor is the device under test (DUT). It shall be investigated how the behavior of the inductor changes with dc bias.

The impedance measurement is set up as an One-Port impedance measurement using the Bode 100. The measurement frequency range is set from 100 Hz to 1 MHz. A Full-Range open/short/load calibration is performed using the default settings. The format of Trace 1 is set to Magnitude and Trace 2 is set to Phase(°).

The DC1000 current source is attached to the DUT and switched on before the Bode 100 is connected to the DUT.

NOTICE

First connect the DC1000 to the DUT and configure the DC current **before** connecting the Bode 100.
Turn-on and turn-off voltage spikes could harm the Bode 100 output.

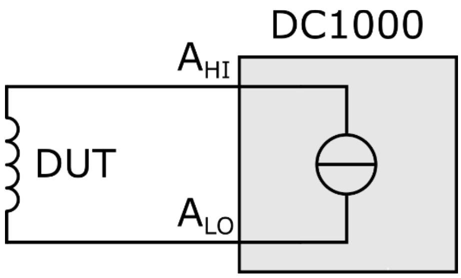

Figure 2: Connection of the DUT to the DC1000

Now the output of the Bode 100 is attached to the DUT as shown in Figure 3. In addition, the DC1000's earthing socket is connected to the earthing socket of the Bode 100 (on the back of the instrument) using a short cable, as it is recommended in the DC1000's user manual.

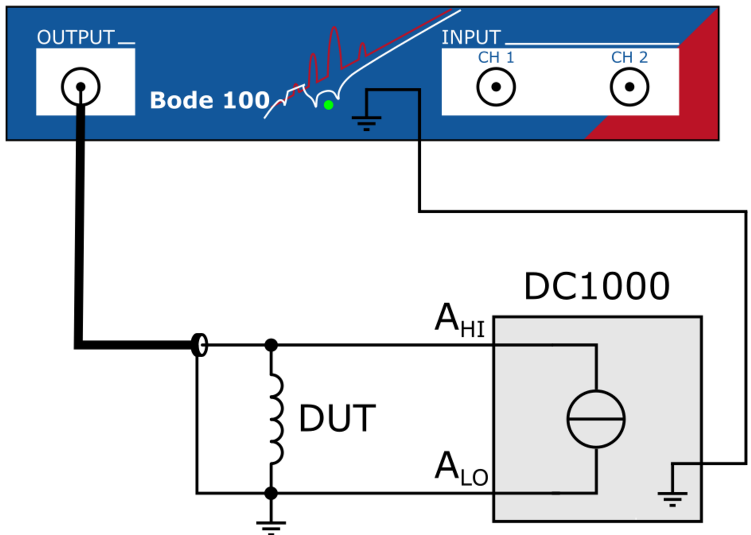

Figure 3: Measurement setup with Bode 100 and DC1000

3 Measurement Results

A NKL 470 µH inductor is measured from 100 Hz to 1 MHz. Figure 4 shows the impedance magnitude at different values for the dc current. The dc current is adjusted accordingly using the setting wheel at the DC1000 current source. The magnitude decreases with dc bias and the inductance is also decreasing following the relation for an ideal inductor

$$Z = j\omega L$$

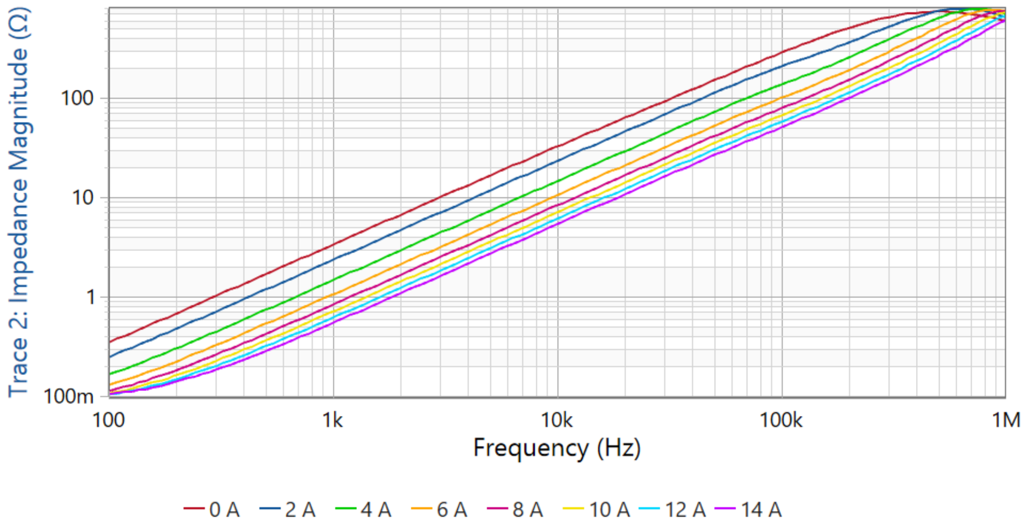

Figure 4: Impedance magnitude of the inductor versus frequency

Figure 5 shows the impedance represented as inductance Ls. The decrease of inductance with dc bias is clearly visible.

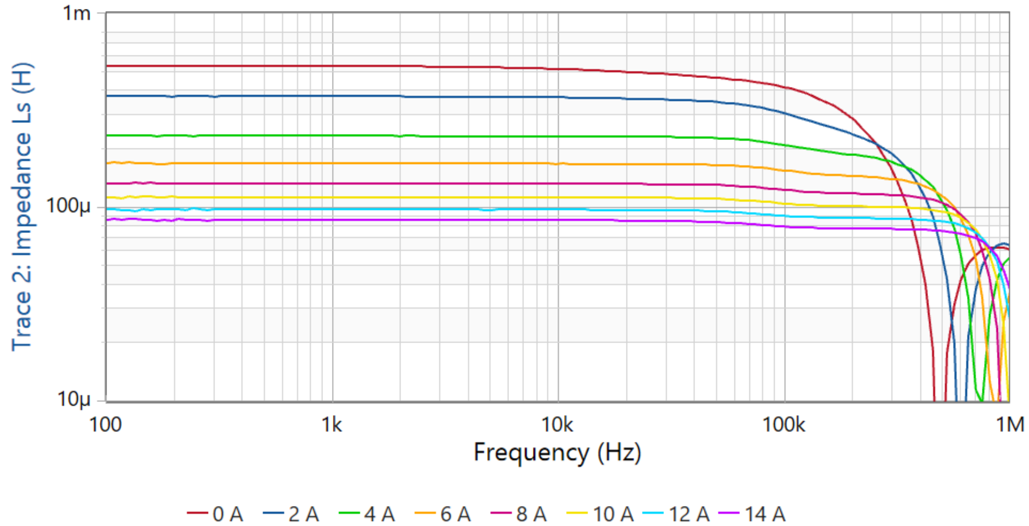

Figure 5: Inductance versus frequency for different dc bias current values

Figure 6 shows the nominal inductance versus DC bias current, measured at 10kHz. The blue curve shows the inductor measured in the previous section. The other two curves show two additional inductors. Both the 470 µH (blue) and the 700 µH (green) inductor have a rated current of 5 A. The 15 µH inductor (red) has a rated current of 30 A. For all three inductors the inductance drops significantly even below the rated current.

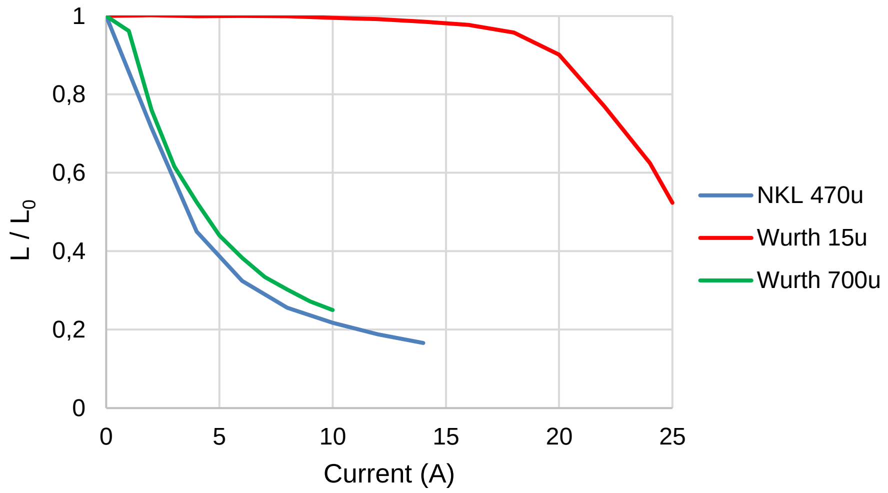

Figure 6: Inductance referred to the inductance without dc bias versus current; measured at 10 kHz

Figure 7 shows the inductance referred to the inductance without dc bias on the vertical axis and the current referred to the rated current on the horizontal axis. The measured inductors are the same than before. The inductances of the 470 µH and the 700 µH inductors drop by more than 50% at the rated current. The inductance of the 15 µH inductor drops by 40 % at 80 % of the rated current, which is the maximum current the dc source can provide (25 A).

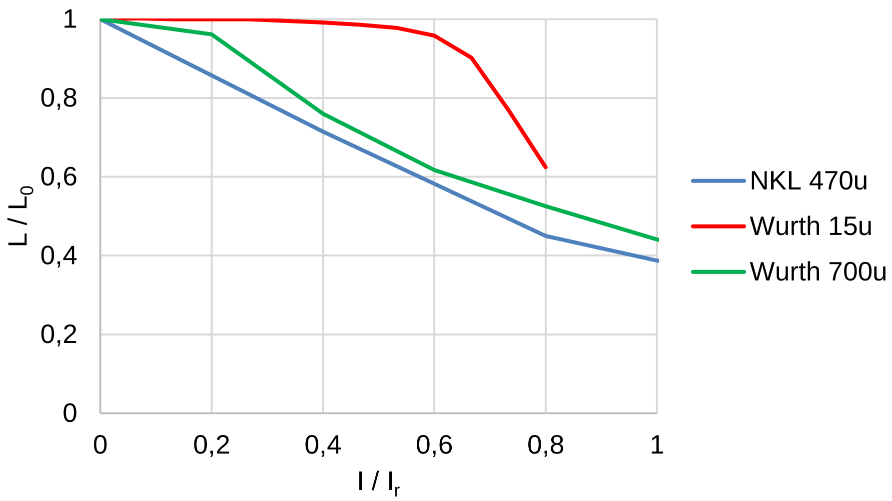

Figure 7: Relative inductance at 10 kHz over relative bias current (referred to the rated current).

4 Bias Source Measurement Error

Any current source, also a dedicated DC bias source, has a finite output resistance or output impedance that causes an error when performing the measurement shown in this document. The VNA will not only measure the DUT but a parallel circuit of the DUT and the current source.
Figure 8 and Figure 9 show the magnitude and the phase of the impedance of the 470 µH inductor. The blue curve shows the impedance of the DUT measured without the current source. The red curve shows the impedance of the DUT and the parallel current source. The current was set to 0 A. The magnitude starts to deviate above circa 100 kHz and the phase even below 10 kHz. The higher the impedance magnitude, the higher the measurement error caused by the paralleled current source impedance. This should be considered especially when measuring the series resistance.

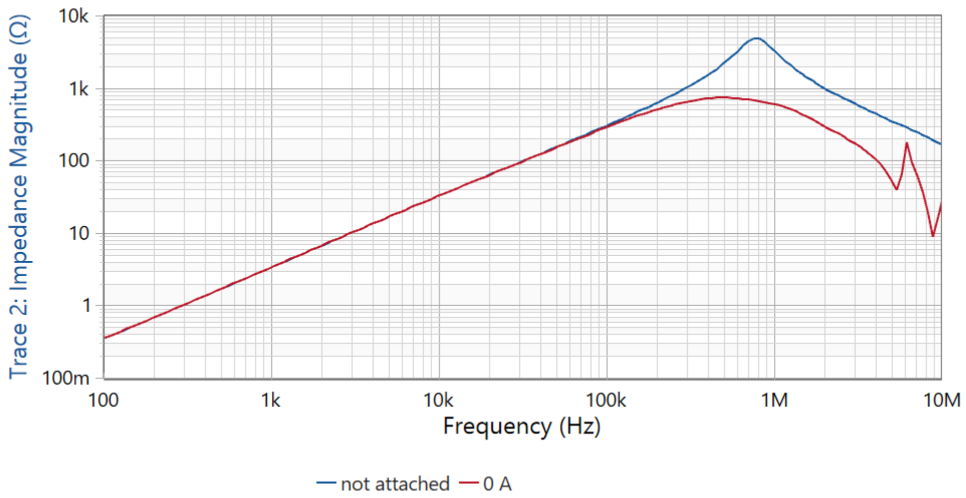

Figure 8: Impedance without DC source (blue) and with DC source (set to 0 A) in red

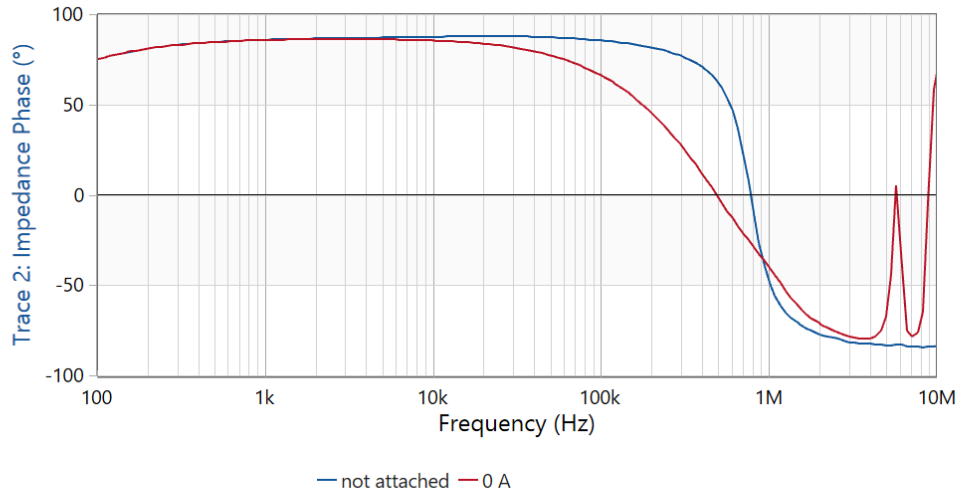

Figure 9: Impedance phase without DC source (blue) and with DC source (set to 0 A) in red

Figure 10 and Figure 11 show the same measurement as before this time the impedance is represented as inductance and series resistance. While the inductance measurement provides valid results up to about 50 kHz, the resistance measurement starts to deviate at several kHz and shows almost a factor of five at 100 kHz.

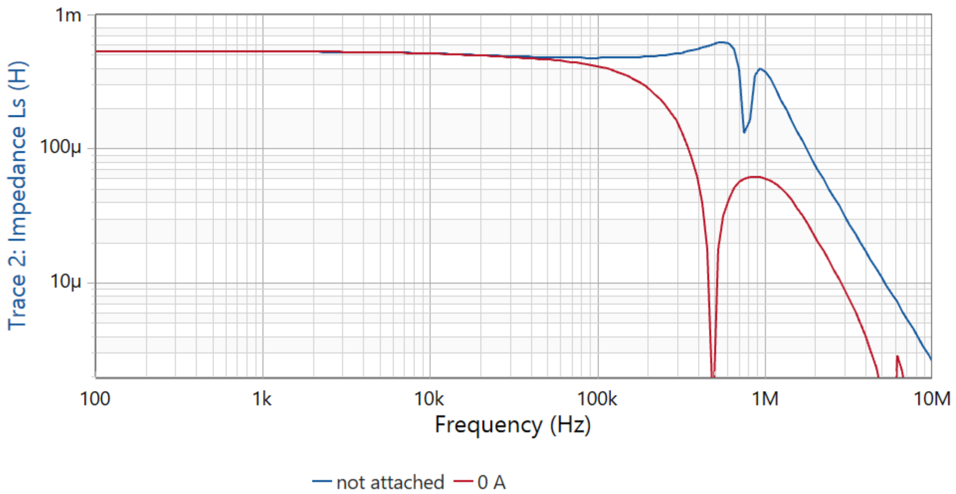

Figure 10: Inductance without DC source (blue) and with DC source (set to 0 A) in red

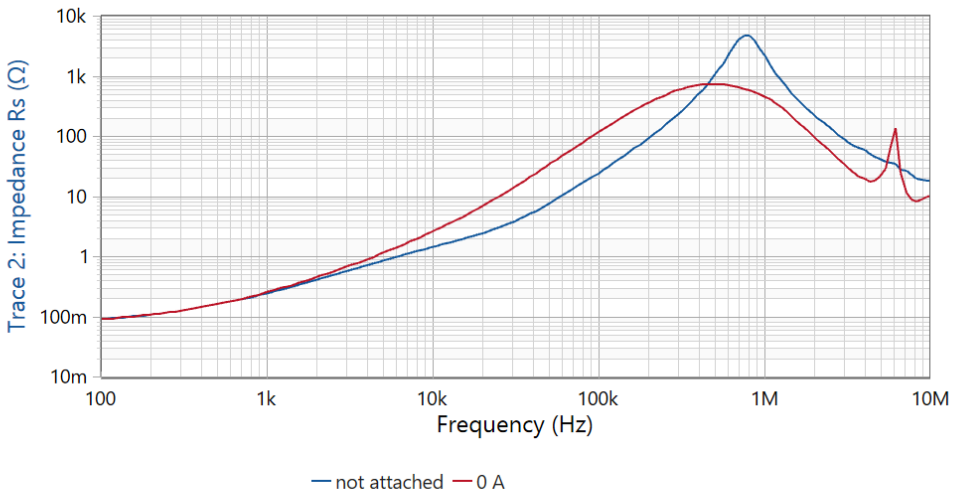

Figure 11: Series resistance without DC source (blue) and with DC source (set to 0 A) in red

5 Conclusion

The usage of a current source to measure dc biased inductors can provide valuable information about core saturation and thus the inductance as a function of the dc current. The performed measurements show that some inductors can exhibit an inductance drop of 50 % or even higher at the rated nominal current. Measurement errors induced by the parallel circuit of the DUT and the current source can occur and should be considered. Especially when measuring the series resistance or the inductance at higher frequencies the error can be significant. When using an arbitrary current source which is not specially designed for dc biasing the error can be even higher due to the tendentially lower output impedance.

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